

Enhanced Target and Clutter Separation by Sensor and Data Fusion

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Introduction

In developing systems whose purpose it is to protect aircraft from missile attack, an important problem is the detection and tracking of small missiles, where the missiles approach the aircraft at high speed, and in a high clutter environment. The goals are to: (1) detect the presence of a missile, (2) correctly identify the missile (and in particular not mistake a missile for clutter), and (3) track and jam the missile effectively.

This paper discusses goal (2), describing improvements in the ability to separate IR targets from clutter, due to employment of sensor and data fusion. These techniques are utilized in conjunction with more standard techniques which are specific to individual sensors, including matched filtering (spatial or spectral), windowing, gating, integration, and adaptive thresholding.

Fusion Benefit

The expectation of potential benefit with this approach is based on the utilization of multiple sensors and characteristics. The sensors employed may span regions in space, time, or spectrum that are disparate or that overlap in whole or in part. The sensor's measurement characteristics may also differ for parameters such as field of view, field of regard, sampling rate, frequency resolution, angular resolution, quantization accuracy.

An example of the potential benefit of sensor and data fusion may be in fusing data from IR and UV sensors. In this case, the fact that the frequency response peaks of IR and UV sensors occur at different wavelengths may be exploited by utilizing information from both sensors to differentiate among and classify, sources which radiate primarily in the IR, or the UV, or in both domains. Sensor fusion also allows improved track confirmation and continuity. For example, one sensor type can maintain a track that might otherwise be lost by a different sensor type due for example to effects such as atmospheric obscuration. These factors result in higher confidence probability of detection, improved suppression of false alarms, and thus enhanced survivability.

Approach

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The approach may be summarized as consisting of: (1) understanding the parametric domains of the observables generated by the system's sensors, (2) maximizing the synergistic payoff by combining the sensor data, (3) applying processing functions and statistical estimation algorithms to develop ranked hypotheses of tracks, and finally, (4) combining the ranked hypotheses with a priori threat and scenario information to make high confidence level decisions on the lethality/priority of the current threat situation. The Sensor Fusion processing outputs must be developed and reported quickly enough to allow time to be utilized within the system effective performance envelopes.

An assessment of the potential payback of a sensor fusion approach begins with an evaluation of the quality and quantity of the observables provided by each sensor type, and an investigation of the individual sensor properties. Table 1 lists the sensor types in the system and their measured and derived properties.

Table 1: Time/Space/Spectrum: Sensor Characteristics
 <-----Measured Parameters-----><-----Derived Properties----->

Sensor Type	Angular Coverage Az/El	Angular Accuracy Az/El	Spectral Utility	Latency	Range	False Alarm Rate	Detection Probability	Intent / Mode
Cued IR Tracker	P	E	M	M	E	M	N	N
UV Warner	E	E	M	E	M	M	E	E
Scanning IR Warner	E	M	M	M	E	M	M	E

E= EXCELLENT M = MODERATE P = POOR N = NONE

Sensor Evaluation.

To illustrate the entries of Table 1, the case of a scanning IR warning receiver will be discussed in more detail.

The IR receiver is a scanning sensor which has large angular coverage (e. g., a quadrant) in intervals of the order of tenths of a second. Angular accuracies in azimuth and elevation are on the order of a fraction of a degree. A standard method of reducing false alarm rate is to integrate the observations over time. For example, a valid detection may require observation of the signal over two or three consecutive scans. With regard to latency, as the enforcement of threat validation criteria becomes more stringent, the latency time between observations tends to increase. Derived (or computed) information such as threat intent, or time to intercept, may be obtained on the basis of consecutive observations. Rough range of the observed object may be computed on the basis of intensity of the object, if the type of the object has been identified (e. g., by other means). The IR sensor also addresses attributes such as burn time and engine thrust, which may be utilized to discriminate between aircraft and missiles.

Synergy of Paired Sensors

In general, it is expected that the fusion of diverse information from multiple sensor types in the system (and from other potential sources outside the system) enables decisions to be made with higher confidence (relative to sensor information alone) on important issues such as: false alarm suppression, feature detection, feature to threat classification, and prioritization of multiple threats. An integrated system enhances the confidence level of decision regarding the identity, spatial locations, and intent of detected threat(s). The enhancement in platform survivability afforded by the sensor fusion approach may be traced to the relative synergistic improvements provided by paired sets of sensors, illustrated in Table 2.

Table 2: Sensor Synergy Matrix

	Cued IR Track	UV Warning	IR Warning
Cued IR Track	X		
UV Warning	(Med - Hi)	X	
IR Warning	Lo	(Med-Hi)	X

Low Synergy

The synergy is generally assessed as Low when the two sensors are overlapped in their measured coverage. For example, the spectral coverage of the 1-color IR warning receiver is overlapped with that of the cued IR tracker. The presence of a signal in both sensors provides some redundancy and false alarm reduction.

Medium-High Synergy

Medium-high synergy is assessed when paired sensors are employed such that (1) the sensors have disparate spectral coverages, and (2) the sensors differ substantially in resolution. For example, the cued IR sensor has high angular resolution and thus capability for following angular rate of change. Hence the presence of a signal in both the cued IR and the cued UV warning sensors, particularly if it has persistence, is judged as med-high synergy. This means a medium-high confidence that the system will make the correct decision on whether an observation is a threat or a false alarm.

As the overlap in parametric coverage increases, the synergy tends to decrease. For example, there is more spectral overlap between 2-color IR and 1-color IR sensors than there is between either of these and a UV sensor. Hence the cued IR track synergy with the 2-color IR warning sensor is assessed as medium.

Fundamental Assumption

The fundamental assumption of the present approach is that there are systematic differences between missiles and clutter, as regards a number of observables (or discriminants), as measured by various sensors. For example, the IR signature of a missile in flight certainly differs from that of most IR background clutter, most of the time. The intensity is not, however, the only measured quantity which is useful as a discriminant in separating targets from clutter. We have selected seven such quantities: (1) Intensity (2) Intensity Rate (3) Increasing Intensity Trend (5) Decreasing Intensity Trend (5) Line of Sight (LOS) Rate (6) Feature Size (pixels) (7) Rate of Change of Size (pixels per second).

Systematics of Missile and Clutter Differences

The systematics of the differences between missile and clutter are obtained by operating on missile live-fire test data, and on clutter measurement data. This data is processed and reduced statistically, resulting in characteristic curves representing the probability of occurrence of each of the seven parameters above.

Typically the processing consists of operating on missile and clutter time profiles. These are fitted with smooth curves, and then utilized to generate occurrence histograms, to yield for example the probability of occurrence of a given interval of intensity. The missile probability is then obtained by calculating the percentage of time a given intensity interval occurred for missiles, as compared to all occurrences including clutter.

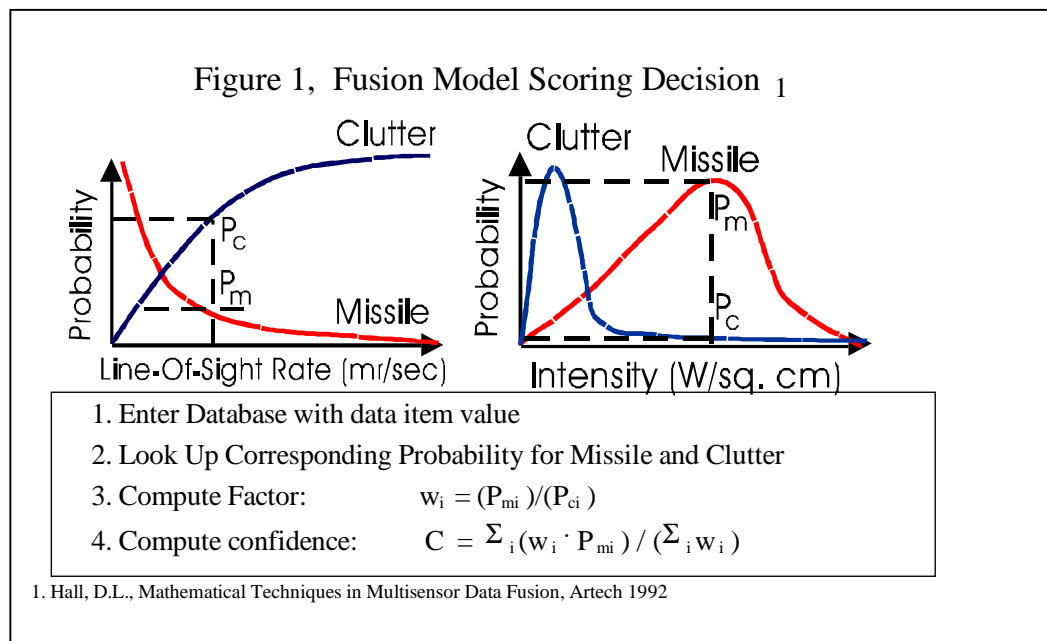
System Operation

During system operation, the observables flow in from the different sensors systems to the target recognition processing at a given rate, coming either directly from the sensor or derived from the sensor report. False alarm recognition processing proceeds as follows:

1. Read the observed or derived observables.

2. Find the probability of occurrence of each observable by table look up in the pre-stored characterization tables.
3. Compute the aggregate missile confidence factor obtaining the average probability of occurrence of all participating observables.
4. Classify the tracked object as a missile or false alarm by testing the average confidence against a threshold. The threshold will be based on the mean and standard deviation of the confidence factor distribution (a Gaussian, by the Central Limit Theorem).

A diagram illustrating the target recognition processing for the Intensity and LOS rate is shown in Figure 1. The red and blue curves represent the characterization data for missiles and clutter, respectively. The dashed lines indicate how a particular observation is utilized to look up the missile and clutter probability, which are then used to calculate the aggregate confidence factor average.



Need For Multiple Discriminants

In order to maintain good separation between missile and clutter over different operational conditions, including different types of clutter and types of missiles, multiple discriminants are employed. The need for this may be demonstrated by Figure 2 and 3, showing missiles in an urban clutter background. Figure 3 shows only the pixels whose intensity exceeds a maximum threshold value. Note that even in this case there is clutter which persists, potentially impacting the missile clutter separation efficiency.

Figure 2: Missile in (a) Urban and (b) Desert Clutter

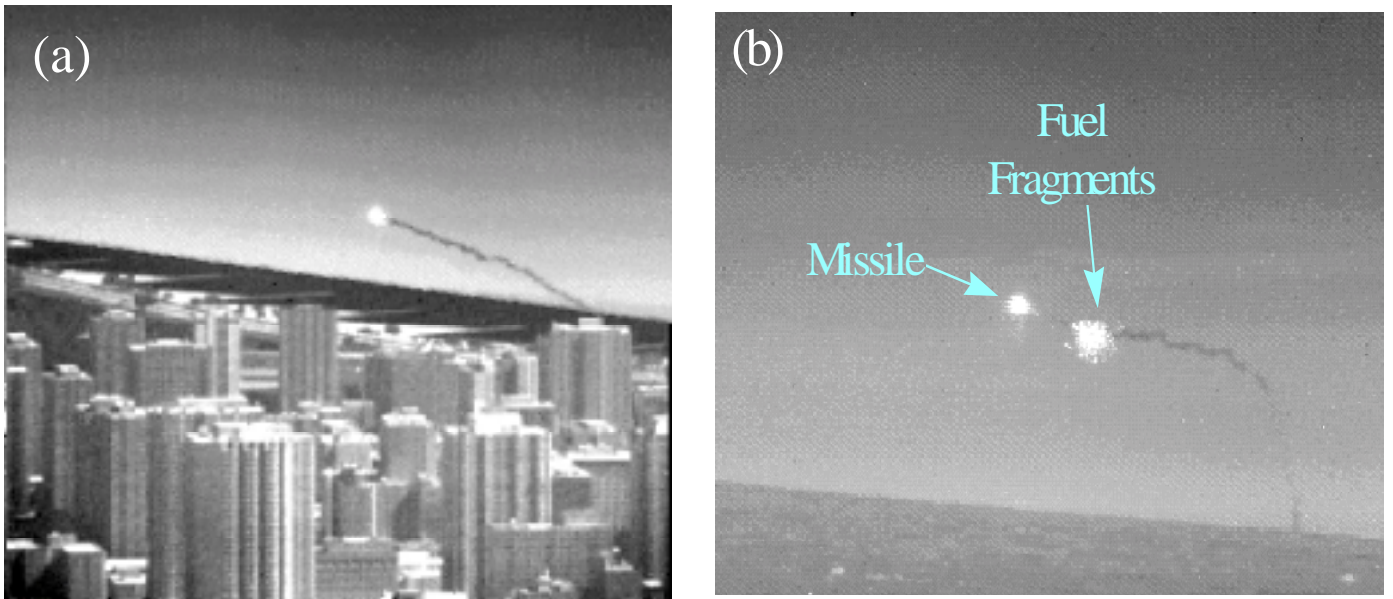
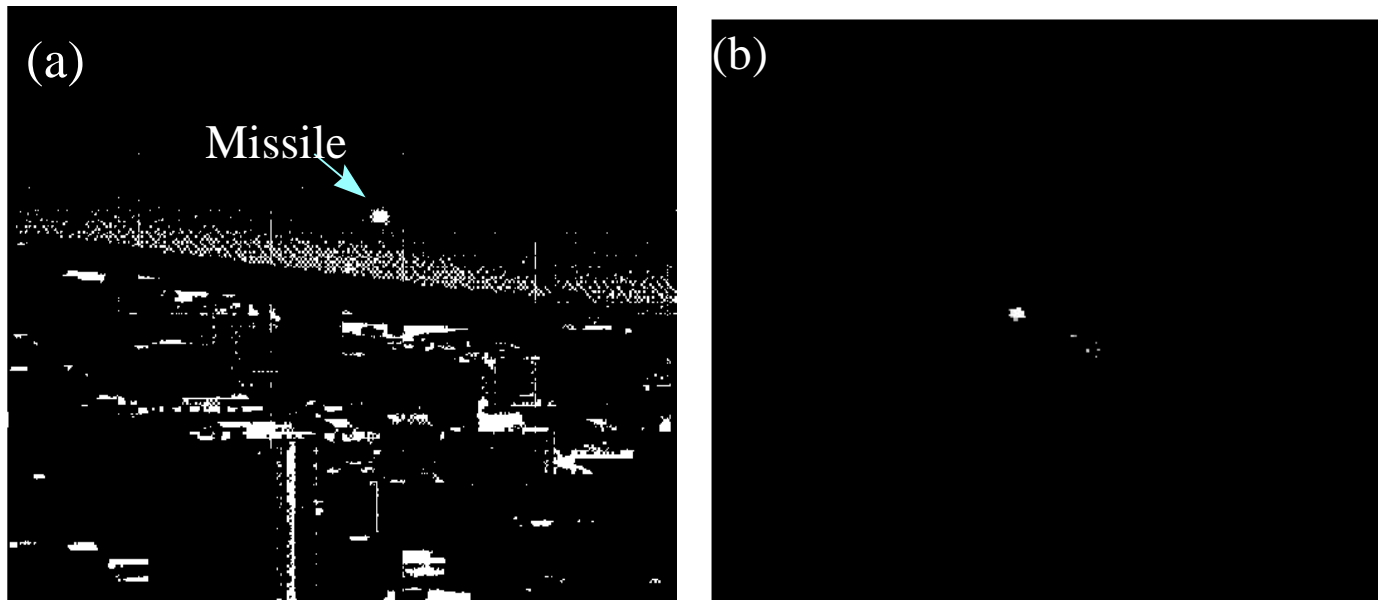


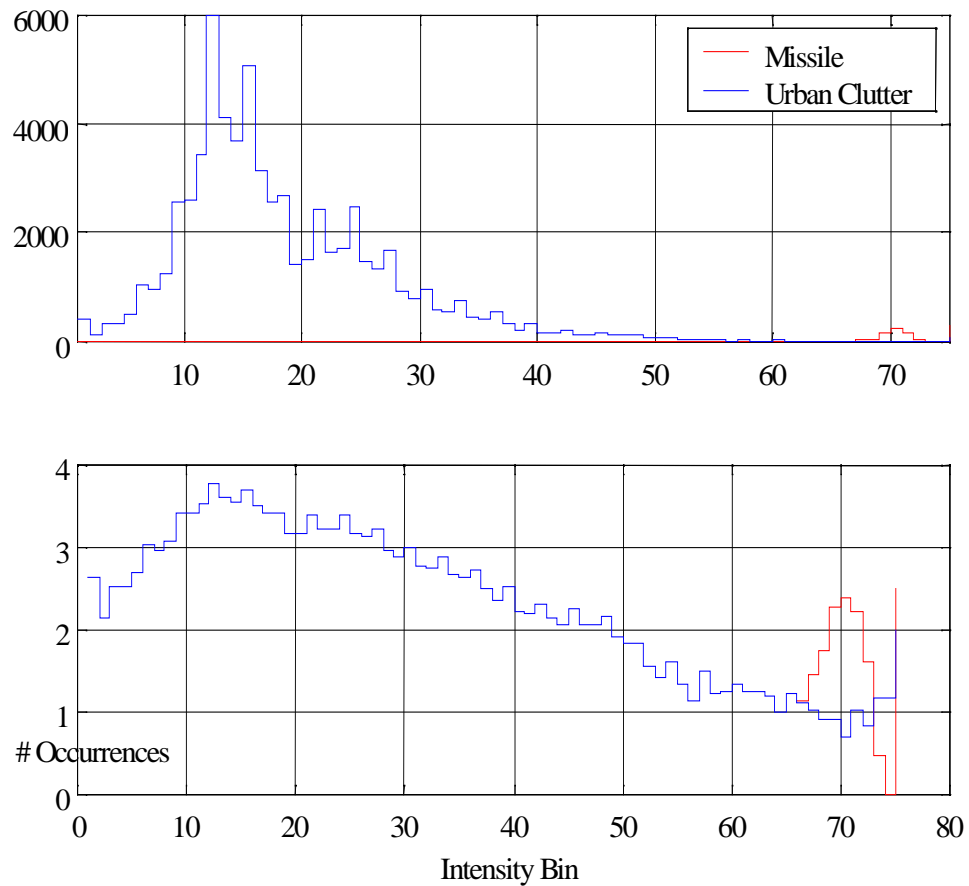
Figure 3: Missile in (a) Urban, (b) Desert Clutter - Thresholded at Maximum Intensity



The reason for the contamination may be seen in Figure 4a, showing histograms of the IR intensities of missile and clutter. While the missile intensities are, as expected, much higher than the clutter, there is a tail in the clutter histogram that extends to high intensity. (The tail may be more clearly seen in Figure 4b, which plots the histograms of Figure 4a on a log scale). This shows

that the thresholding cannot eliminate the clutter, based on intensity alone. In addition, limited dynamic range may result in saturation of the missile intensity, which has the effect of bringing the missile and clutter intensities closer together, making their separation more difficult.

Figure 4a & b Histogram of Missile and Clutter Intensity

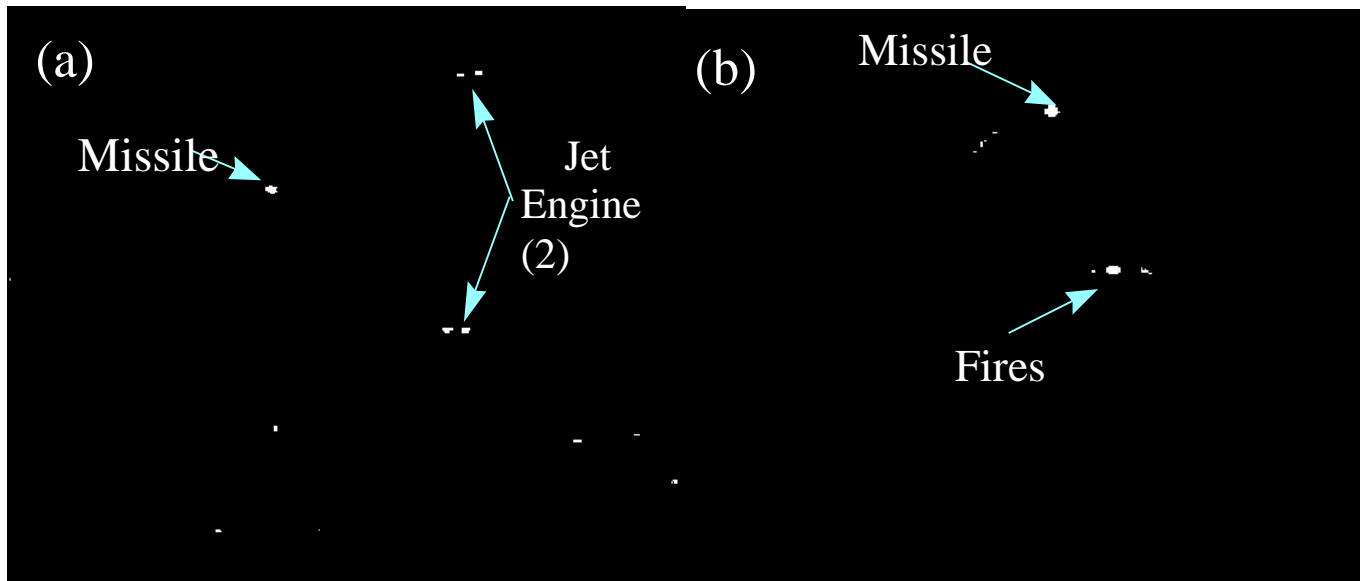


Figures 5 and 6 are additional examples of high clutter intensities leaking into the data, showing this effect for different clutter (jet engines and fires) and missile types.

Figure 5 Missile Against (a) Jet Engine and (b) Fire Background



Figure 6 Missile Against (a) Jet Engine and (b) Fire Background (Thresholded For Maximum Intensity)



Characteristic Curves

Data was taken on more than a dozen missile shots utilizing two sensor types, (1) a high resolution IR imaging camera, and (2) a UV sensor system. Similar measurement equipment was utilized to gather clutter data, as part of a clutter measurement program designed to gather data spanning a range of environmental conditions, from “benign” to “high stress” clutter. The two sensor systems of course covered different spectral regions, and both measured aspect angle, LOS rate, size, and size rate. This data was analyzed as was previously described, and was utilized to generate characteristic curves, one for each of the seven discriminants, each of which yielded the missile probability versus a the discriminant.

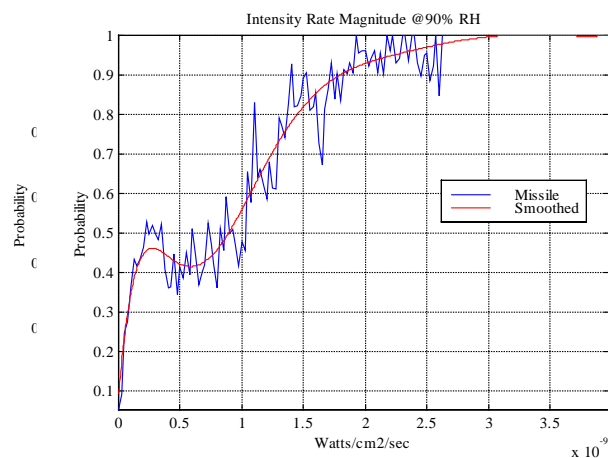
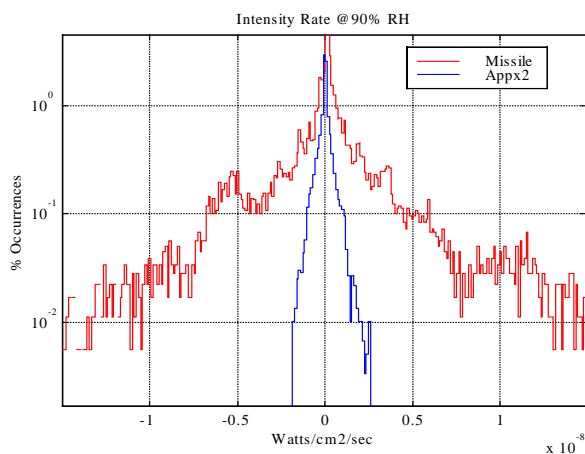
The seven characteristic curves (or tables) are the essential ingredient for achieving the “enhanced separation of missile and target” referred to in the title. The separation is accomplished by simply looking up the missile probability for (up to) seven discriminants, where the discriminants are obtained from the reports coming from the sensor data; they are utilized as indices into the characteristic curves. Finally, the overall missile probability is obtained by averaging the individual probabilities, including possible utilization of weighting factors.

This procedure is “front loaded” in that nearly all the work goes into the generation of the characteristic curves, which is done ahead of mission time. The product of this, the curves or tables, are then stored on-board. The final answer the question of interest: “Is it a missile?”, is a matter of (up to) 7 table look-ups, a weighted average calculation, and a threshold comparison. These tasks consume very little processing time.

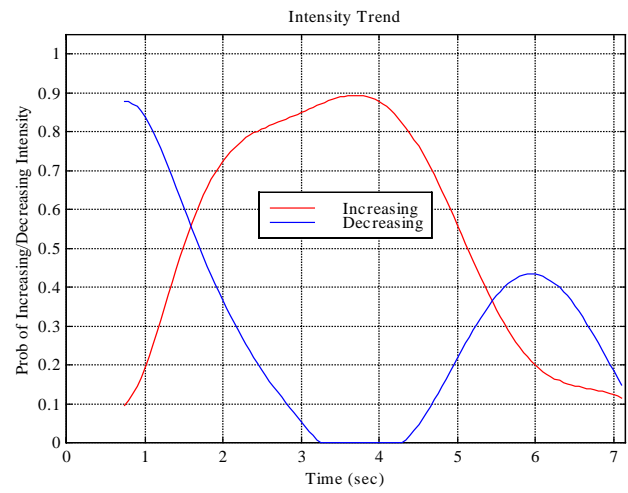
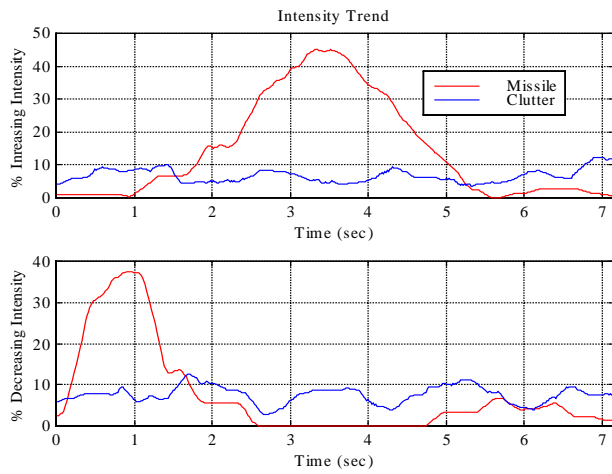
Plots of Missile/Clutter Differences and Probability

Plots of the differences between missile and clutter for each of the 7 discriminants are presented below, shown on the left. Plots of the corresponding missile probability for each discriminant are presented below, shown on the right.

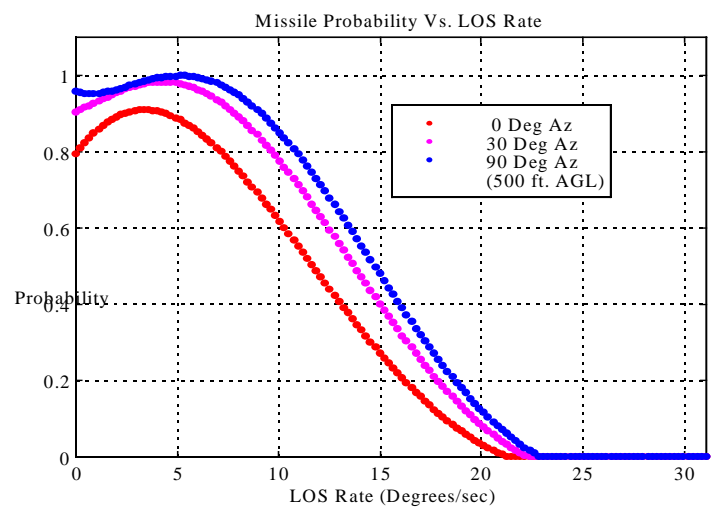
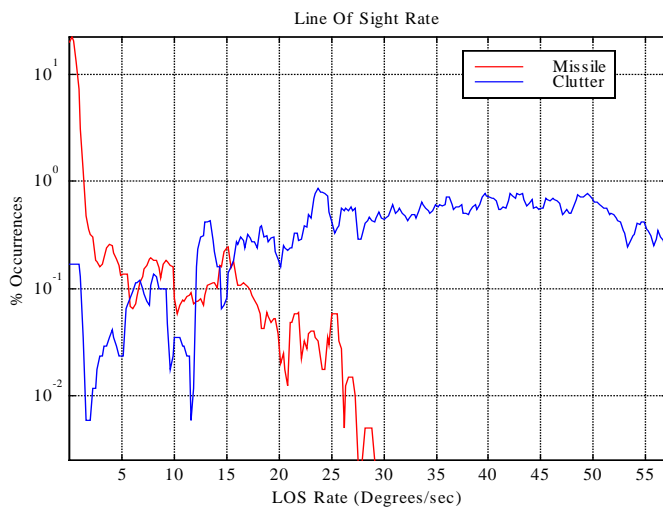
Intensity 00
Intensity Rate



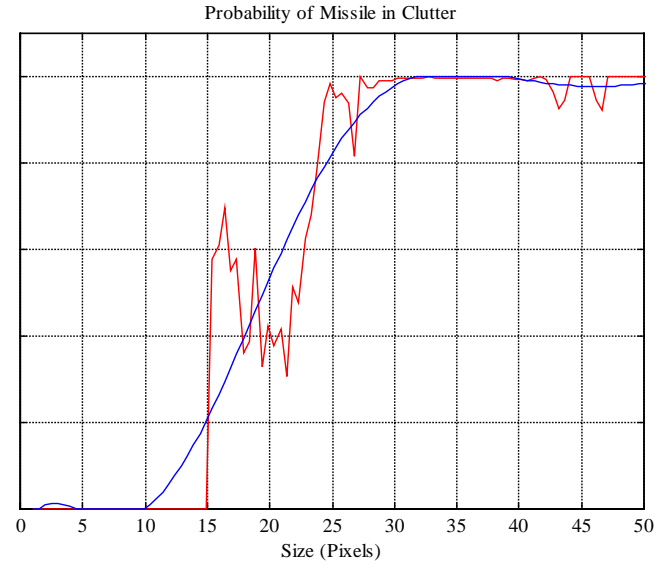
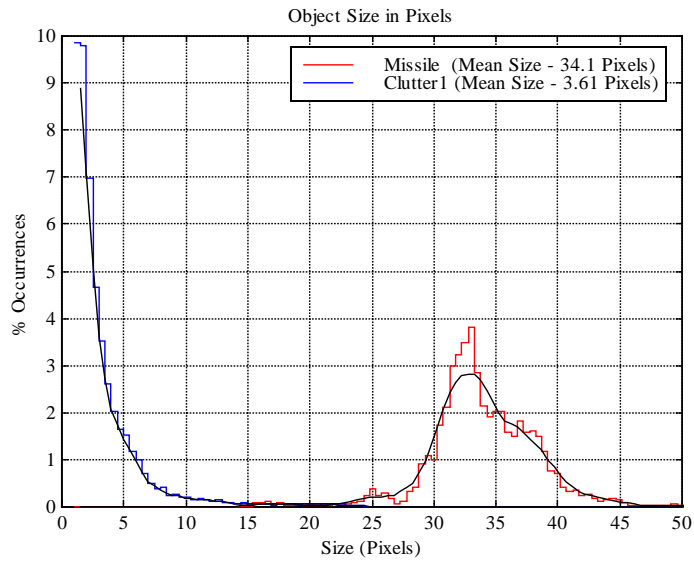
Increasing and Decreasing Intensity Trend



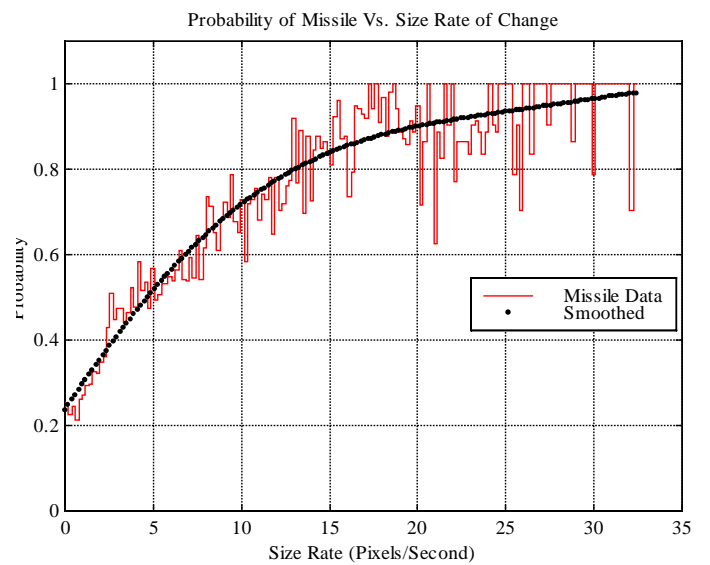
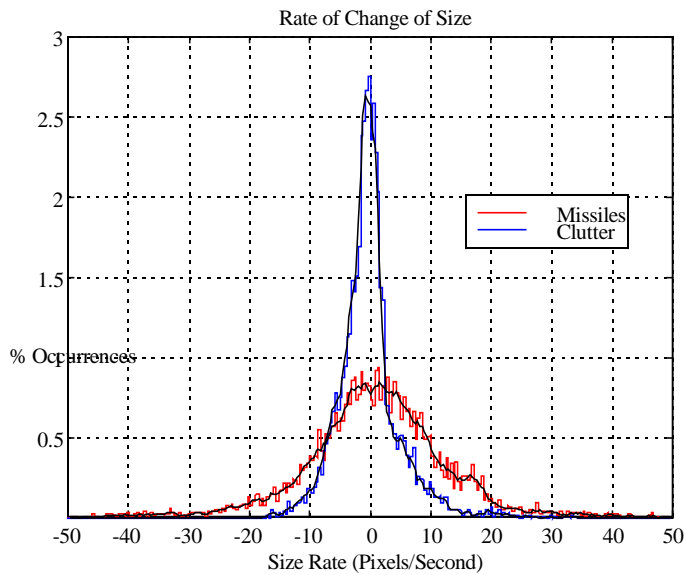
Line of Sight (LOS) Rate



Size

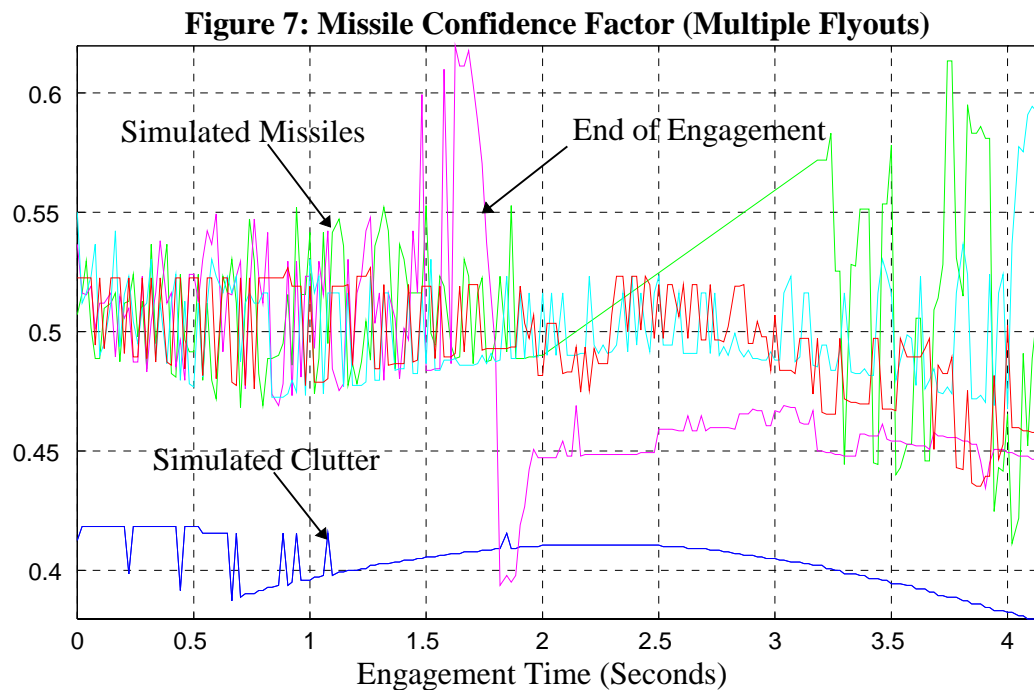


Size Rate



Preliminary Laboratory Test Results

Preliminary laboratory test data has been collected where simulated missile and clutter inputs are generated. These are then operated on according to the procedure described above, resulting in the output: missile probability as a function of time. Figure 7 shows a preliminary laboratory test plot of the missile probability for a simulated missile and simulated clutter. Differences between the two are evident, which was expected. There are also cases of probability overlap. It is expected that as the lab testing proceeds, including implementation of planned upgrades in the lab simulations, the differences will be clearer and more pronounced and the occurrences of overlap greatly reduced.



Conclusion

A method has been described by which missile targets may be separated from background IR clutter with enhanced efficacy, based on utilization of sensor and data fusion techniques. The method takes advantage of regularities in empirical data on missile and clutter observations. The method has been applied to simulated data and laboratory data with good results.